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(57) Abstract

The invention relates to a method for predicting the traffic flow in a road network. Sensors in the road network register the passage of vehicles and two of the parameters, flow, density, speed enable all three parameters to be calculated. The correlation between the traffic at a point X at a certain time and the traffic at another point Y some period τ later can in certain cases and under certain conditions provide good values. In these cases, the traffic can also be predicted with good precision. The invention utilizes this fact and relates the prediction factor to the correlation coefficient. The invention also uses the methods to divide a traffic parameter into various frequency components to be used in various situations and improves the prediction by using the corresponding prediction factor for the corresponding frequency components of the traffic parameters. For the predictions, sensor information from different links is used in some cases to provide a quicker and more effective prediction by means of cooperation. The method for providing this cooperation also belongs to the invention. In certain sensor-lean situations, the prediction factor described previously is supplemented with a propagation factor W that describes the traffic changes along a traffic link, and where W can be defined and adapted to the various frequency components of a traffic parameter.

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PREDICTION METHOD OF TRAFFIC PARAMETERS

The present invention relates to a method for determining the state of vehicle traffic along traffic routes and road networks. The method can also be applied to predict traffic states with the aid of the latest measuring data obtained and earlier measured values. Prediction is important, since it creates conditions which enable appropriate measures and procedures to be adopted and the traffic to be controlled in a manner to avoid immanent traffic problems. Prediction is also important from the aspect of vehicle or transport control, in which route planning and the selection of the best roads at a particular time is effected preferably with respect to futuristic traffic situations when the vehicles concerned are located on respective road sections.

Incidents and events that occur can also have a great influence on prevailing traffic, and a prediction of a change in traffic flow will provide a basis on which to make a decision as to which control measures should be taken, for instance by broadcasting information over the radio or through the medium of changeable road signs.

Various methods of determining traffic flows are known to the art. The OD-matrix based methods have long been used to calculate traffic flows under different circumstances and in a long-term future perspective. These methods are used, for instance, in city-planning projects, road planning, etc., and the futuristic perspective can apply for several years.

OD stands for Origin Destination and an OD-matrix which describes how many vehicles are driven from an origin O to a destination D per unit of time and the routes used by these vehicles can be generated by using the knowl-

edge of domestic areas, work places, travel habits, etc., and by measuring the traffic flows.

The information basic to OD-matrices is difficult to obtain. For instance, the method is used to produce the average values over a period of one year, and the accuracy can be improved successively by calibrating the assigned values with regard to the values actually measured.

Those predictions with which the present invention is concerned are predictions which cover much shorter time periods, for instance time periods of from 1-3 minutes up to the nearest hour, and with successively less precision for the nearest day. Historically typical traffic curves which are modified with regard to known obstructions, interference, road works, etc. are used in the case of time periods longer than one calendar day. The nature of traffic is such that the best way of predicting traffic over a longer time perspective is to say that the traffic will be as usual at the time of the day, on that week day, at that time of year, and so on. To this end, it is essential to take many measurements and to store significant average values for traffic on the road network links for different time periods. Such a data base can also be used conveniently together with the present invention.

The use of OD-matrices has also been discussed for short time perspectives, such as those applicable to the present invention. This is encumbered with a number of problems. A great deal of work is involved in defining different OD-matrices for each short time period of the day. At present, there is no reasonable assaying or measuring method which assays the origins of the vehicles, the destinations of the vehicles and the routes travelled by the vehicles. Methods of enabling

the journeys of individual vehicles from O to D to be identified and followed have been discussed. A traffic control system in which all vehicles report to a central their start and destination and also their successive respective positions during their journeys has also been proposed.

Present-day measuring sensors can be used when practicing the present invention. Another fundamental principle of the invention is one in which the parameter values used are constantly adapted to the current measurement values, so that the system will automatically endeavour to improve its accuracy and adapt itself successively to changes in travel patterns, traffic rhythms, road networks, and so on.

Many mathematical processes have earlier been tested on different traffic problems. In this regard, misunderstanding with regard to the nature of the traffic and the inherent stochastic character of the traffic is not unusual. More advanced methods and more comprehensive calculations are unable to predict traffic more precisely than those limits that are set by the "noisiness" of the traffic. If a parallel with electronic measuring techniques is drawn, this would be similar to attempting to obtain more signal from electronic noise by using more finely-tuned methods.

Once having accepted that noise is noise, this knowledge can be very useful. It enhances the understanding of how traffic can be managed and predicted. The parameter values used to characterize noise include, for instance, the average values and variances that can be calculated from the noise distribution function. Naturally, there is nothing wrong in using qualified methods such as the Kalman filtration method for instance, which can also be applied in the present invention. It is essential that

the methods are used for the right type of problem and with an adapted model of reality.

Vehicle traffic simulating programs have also been developed. These programs are often used when dimensioning street crossings, slip-ways to and from highways, motorways, etc. The stochastic nature of the traffic is expressed here by using random number generation to randomly select the positions and start times of individual vehicles, driver behaviour factors, etc.

The result obtained is one example of the possible state of the traffic, depending on the model and the randomly selected parameters applied. It is possible to obtain some idea of how the traffic tends to flow in a road crossing or road intersection, for instance, with a larger number of simulations, and therewith modify the road crossing or road intersection already at the planning stage.

As will be apparent from the above example, this type of simulation will exemplify the possible futuristic state of the traffic. This shall be compared with a prediction which is required to provide a solution that lies within the most probable result area, including an understanding of relevant variancies.

The invention is characterized by the features set forth in the following Claims.

The invention will now be described in more detail with reference to the accompanying drawings, in which

Figure 1a illustrates a simple model of a control centre having only one operator site;

Figure 1b illustrates an example of a control unit included in the traffic model unit;

Figure 2 illustrates data flow and functions for prediction and updating purposes;

Figure 3 illustrates sensor information delivered to the control centre;

Figure 4 illustrates prediction by a link in a first stage;

Figure 5 illustrates prediction of several links in a subsequent stage;

Figure 6 illustrates updating of historical values X_H in a database;

Figure 7 illustrates how the traffic parameters can be processed to produce function values included in obtaining the correlation coefficient and the prediction factor; and

Figure 8 is a simplified example of a road network which includes approach roads or entrances to a city centre.

The present invention will be described first with reference to an exemplifying embodiment thereof in which simplicity in both description and construction has been given priority so as to facilitate an understanding of the fundamental nature of the invention. This initial description will then be followed by a detailed description of other embodiments. This is done with the intention providing a pedagogical explanation rather than giving priority to the merits of the invention.

Implementation of the invention is based on the availability of measuring sensors. Since measuring sensors can represent a large part of the costs involved, embodiments are also included in which the road network has a low sensor density, while still enabling the system to produce useful information, although perhaps less precise and with a higher error probability in the predictions.

A Simple Example of One Embodiment

The traffic situation in and close to large towns and cities represents one example of the area in which the invention can be used. In this case, the road network is divided into different parts or sections having different properties or qualities and of different significance from a traffic technical aspect.

A. Large traffic routes - for traffic entering and leaving the city.

B. Traffic arterial roads - for large flows of traffic in the city.

C. Regional networks - connected networks of streets and roads within a relatively unitary region from a traffic aspect.

D. Other traffic routes

E. Narrow roads and streets of less importance from a traffic technical aspect.

Determining Traffic on Large Traffic Routes

The traffic is preferably measured with regard to two of the following parameters:

I = cars/s
P = cars/m
v = m/s,

wherein the third parameter is obtained from

$I = P \cdot v$.

One interesting task is to predict the traffic on a link A on a traffic route on the basis of measurements obtained by sensors on a link B upstream of the traffic route.

The basic concept is that the vehicle traffic in B will reach A after a time lapse of t_1 and that it is therefore possible to anticipate the traffic in A while using the time allowance of t_1.

However, a number of relevant complications occur, which are not normally observed.

For instance, assume that the sensor on link B is located at a time distance of 5 minutes upstream of A. Given that A is equipped with a measuring sensor, it may be found that a given correlation exists between the measurement values in B and those obtained 5 minutes later in A. This does not mean, however, that by measuring traffic in B, it is possible to predict the traffic in A after a lapse of 5 minutes. Five minutes travelling time at a speed of 20 m/s (roughly 70 km/h) implies that the distance covered will be 6 km. This distance will normally include several exit roads and entry roads

close to cities and measuring times in the order of five minutes are usual in order for variances in the measurements not to be large. But if the measuring time is five minutes, this will mean that the first vehicles included in the measurement will already have arrived at A before the measuring process is terminated. If this five-minute prediction is required in order to gain time in which to control the traffic, it is apparent that in the illustrated example a measuring sensor must be placed at a travel distance of 10 minutes from A. This implies a distance of 1.2 metric miles from A, and there are often many factors which influence the traffic during a travel distance of such length, which means that a "one to one" relation between the traffic in B and the traffic in A cannot be expected.

The following complications thus arise:

If the measuring sensor is placed close to A so as to obtain good correlation with the measurement values in B, no prediction time is obtained since this prediction time is consumed by the measuring time. If the sensor is placed far away from A, so as to obtain prediction time, the correlation level is lost.

In the case of the present invention, there is formed the relationship

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$I = I_0+I_1+I_2$

$P = P_0+P_1+P_2$

where I_2 is an average value of the time interval T_2 superimposed on I_0 and I_1;
I_1 is an average value of the time interval T_1 superimposed on I_0; and
I_0 is an average value of the time interval T_0.

Examples of the values are $T_2 = 30$ s
$T_1 = 3$ min.
$T_0 = 15$ min.

For the sake of simplicity, I_0 can be calculated successively as the approximation

$$I_0(t+T_2) = I_0(t) + \frac{I(t+T_2) - I_0(t)}{T_0/T_2}$$

and $$I_1(t+T_2) = I_1(t) + \frac{I(t+T_2) - I_0(t+T_2) - I_1(t)}{T_1/T_2}$$

and $$I_2(t+T_2) = I(t+T_2) - I_0(t+T_2) - I_1(t+T_2)$$

The density values P_0, P_1 and P_2 are calculated in a corresponding manner. The advantage afforded by dividing the flow into three different time components has strong affinity with the object of the invention.

When the measurements taken indicate low I-values and P-values and speeds, v, close to the link permitted speeds, this will normally mean that traffic is moving well and that there is a good margin before the traffic capacity value of the link is reached. In this case, the need to produce highly accurate values is not very pronounced. Traffic management information that is of interest is the expected travel time per link, and when traffic flows with a good margin to the traffic capacity of the link, the link time $t_L = L/v_L$, where L is the length of the link and v_L is the basic link speed, which corresponds approximately to the link speed limit.

In the case of the majority of road links, the link time $= t_L$ will apply in most cases over a twenty-four hour period. The link time can therefore be easily predicted.

It is not until traffic becomes denser and approaches the capacity of the link that more comprehensive analyses are required. (Some exceptions in this regard will be presented later.)

Those instances initially studied here involve situations in which the traffic flow approaches traffic capacity somewhere along the traffic route.

Case a. I_0 and I_1 are small, I_2 is large. This implies a single high density vehicle batch over a short period of time equal to T_2.

Since I_0 and I_1 are small, the risk of large traffic congestions or traffic jams is also small and there is therefore no need for a more accurate analysis.

If v is small and when I_2 is large, this will indicate a small tail-back behind a slow vehicle and it may be of value to follow the development of I_2 along the traffic route.

Case b. I_0 is large.

This implies that the average flow is high over a long time period and that consequently single disturbances can quickly result in traffic congestions. The traffic flow is also characterized by the fact that vehicle density tends to increase and vehicle speed to drop as the traffic flow reaches the capacity of the link concerned.

Case c. I_1 is large, I_0 is small.

I_1 indicates a long period of high traffic flow. If P_1 is high and v is low, there is a long vehicle tail-back which

affects link times and can cause traffic congestions at the approach roads to the traffic route, for instance.

Division of the traffic flows and traffic densities into different components is also favourable in predicting traffic flows. Correlations are an important function in the prediction of traffic flows. We know from experience that the city entry roads and city exit roads are heavily trafficated during the morning and evening rush hour periods, corresponding to working times, and a good correlation between different entry roads can be expected with regard to traffic developments in the morning rush hours.

This correlation applies for the terms I_0 and P_0, whereas I_1, P_1 will probably have lower correlation, and primarily I_2, P_2 should not exhibit any appreciable correlation between different roads or traffic routes.

Traffic Relationship Between Different Traffic Routes

Good correlation is expected between different approach roads or entry routes of mutually the same type with regard to traffic developments during the morning hours. Good correlation is also expected between traffic as it is, for instance, on a Tuesday on one traffic route with how the traffic usually behaves on Tuesdays on the same route.

We are thus able to identify the "sister route" to the route concerned, wherein the traffic situations on these routes can be used under normal conditions to diagnose the traffic on the link concerned.

Historical measurement data on one route is used to define historical mean value curves for respective

calendar days. These curves may, for instance, be comprised of I_0, P_0 curves.

The historical I_{OH}, P_{OH} curves are used to determine the correlation between the links of diffrent "sister routes" with regard to the size (β) of the correlation and the time shift (τ).

The relevant measurement values (I_0, P_0) of the day are related to the historical data of respective links. For instance, $\alpha = (I_{OA}-I_{OH})/I_{OH}$ form the normalized difference value between the values (I_{OA}) actually measured and the historical values. The calculations need not be proceeded with when these values are small for the links and associated traffic routes concerned and when there is normally no traffic problem. Otherwise, the correlation between the α-values for the "sister routes" is investigated to ascertain whether or not there is a significant change in the traffic situation of that day and therewith be able to take such changes into account.

If there is found an associative change on the sister routes, a change in the traffic situation can be expected over a large part of the city. If only one route deviates to any significant extent, a more local change can be expected, although this may fade out.

An Example of Predicting Flow on a Link B

The following example illustrates traffic prediction on a link B.

A limited number of sensors are available. One sensor is located on an upstream link C. Between C and B there are several traffic flow connections towards C and also traffic flow exits from the route. L_1 up to and including L_4 are the sister routes of the route concerned (L_3).

$\beta(L_3, L_1)$ and the $\tau(L_3, L_1)$, etc., are known for the links of the sister routes.

$\beta(C, B)$ and $\tau(C, B)$, i.e. corresponding relationship between the values in C and B along the same traffic route are also known.

Also available are present measurement values from respective sensors, which indicate that it would be of interest to proceed further, since the traffic flows are of a magnitude such that a traffic problem can be expected.

A prediction in B can be obtained from the measurement values obtained in C through the medium of a transfer factor W. Assistance can also be obtained from the sister routes (L_1-L_4) and from the historical and relevant measurement values in B, i.e. in total three different sources of information.

We discuss first the case in which B lacks the provision of a measurement sensor. We assume, however, that we have access to a measurement sensor downstream of B, i.e. on link A, or that a mobile sensor was earlier placed on B and has provided correlation values for historical data to the other two types of information source.

Assume that C is placed so far out on the periphery as to form one of the outermost sensors for detecting morning rush-hour traffic. Otherwise, the flow in C is predicted in a manner corresponding to the way in which the flow in B is predicted and a further outlying sensor may be found, etc.

Historical curves relating to C and corresponding links on the sister routes are correlated in accordance with historical values.

We discuss in the following simple approximative methods of forming the historical values of I_0 and the correlation factors β.

There is obtained from associated repetitive measurements on one link the value $X_i(t)$, and on another link the value $Y_i(t)$. The measurements may be taken once every ten minutes on ten consecutive Mondays, for instance. The mean value formed from these measurements will provide so-called historical curves $X_H(t)$ and $Y_H(t)$ illustrating how the measured traffic parameter varies over a typical Monday.

By forming $\sum_i^N X_H(t_i) \cdot Y_H(t_i+\tau) = Z(\tau)$, where t_1 to t_N are chosen correlation periods, there is obtained the relevant correlation time τ, where $Z(\tau)$ is maximum.

For $\delta X_i(t) = X_i(t) - X_H(t)$ and correspondingly for $\delta Y_i(t)$ there is formed

$$\Gamma = \frac{\delta Y_i(t+\tau)}{\delta X_i(t)} = \frac{\delta Y_i(t+\tau) \cdot \delta X_i(t)}{[\delta X_i(t)]^2}$$

which provides a highly error sensitive system when $\delta X_i(t)$ is small.

Form instead

$$\Gamma_C(t,\tau) = \frac{\sum_i \delta Y_i(t+\tau) \cdot \delta X_i(t)}{\sum_i [\delta X_i(t)]^2}$$

and
$$\Gamma_C(\tau) = \frac{\sum_k \sum_i \delta Y_i(t_k+\tau) \cdot \delta X_i(t_k)}{\sum_k \sum_i [\delta X_i(t_k)]^2}$$

where $X_H(t) = \frac{1}{N} \sum_i X_i(t)$, $(\overline{X}_i(t) = X_H(t))$

and the correlation coefficient $\beta(\tau)$ around the mean curves $X_H(t)$ and $Y_H(t)$ is

$$\beta(\tau) = \Gamma_c(\tau) \cdot \frac{\sigma_x}{\sigma_y}$$

where σ_x och σ_y are standard means around X_H and Y_H respectively.

The correlation coefficient $\beta(\tau)$ has a maximum value of magnitude 1 when X and Y are fully correlated.

$\Gamma_c(\tau) = \beta(\tau) \cdot \frac{\sigma_y}{\sigma_x}$ also includes a set scale factor which is an expression that indicates traffic may be greater on the y-link than on the x-link.

The correlation coefficient $\beta(\tau)$ calculated in accordance with the above may be small despite x and y being strongly correlated. This is because $\beta(\tau)$ is calculated around $X_H(t)$ and $Y_H(t)$, which take-up the strong correlation, and $\beta(\tau)$ therewith indicates that the traffic variations around $X_H(t)$ and $Y_H(t)$ may partly be random variations which do not depend on factors that are common to x and y.

Corresponding correlation coefficients for $X_H(t)$ and $Y_H(t+\tau)$ are calculated by forming the mean value of $X_H(t)$ and $Y_H(t+\tau)$ and calculating $\beta_H(\tau)$ around these mean values for selected correlation periods.

Y_H can also be related to X_H by forming

$$\Gamma(\tau) = \frac{d\ Y_H(t+\tau)}{d\ X_H(t)}$$

The value of Γ_{dH} over a longer time period is formed from

$$\Gamma_{dH}(\tau) = \frac{\sum_i \frac{d_{YH}(t_i+\tau)}{dt} \cdot \frac{dX_H(t_i)}{dt}}{\sum_i \left(\frac{dX_H(t_i)}{dt}\right)^2}$$

In the calculation of $\beta_H(\tau)$ above, the maximum and minimum values of $X_H(t)$ and $Y_H(t+\tau)$ of the curves have been emphasized. The paremeter $\Gamma_{dH}(\tau)$ instead emphasizes the time derivatives, the flanks on the $X_H(t)$ and $Y_H(t)$ curves. One method of amplifying the requirement of correlation is to use the derivative when this gives greater assistance and the amplitude when this gives greater assistance. In the case of a sine curve, the transition will then occur at $n\pi/4$.

If more sister routes can be correlated to the traffic route concerned, there is obtained correspondingly more measurement values of the X-type, coupled to the values y for the link concerned, and Γ for the sum of the contribution of the sister links can be obtained from the equation

$$\Gamma_s = \frac{\Sigma\ \Gamma_i \cdot \delta X_i}{\Sigma\ \delta X_i}$$

However, if some sister links have a higher correlation than others, these links should be given a higher weighting than when summating for Γ_3 above.

Set $\quad \delta X = X_1 + X_2$

$\delta Y = Y_1 + Y_2$

$Y_1 = k_1\ X_1$

X_1 and Y_1 are correlated with the correlation coefficient 1 and X_2 and Y_2 are "noise variations", i.e. not correlated.

There is then obtained

$$\beta = \frac{k_1 \quad \overline{X_1}^2}{(\overline{X}_1^2 + \overline{X}_2^2)^{½} \cdot (\overline{Y}_1^2 + \overline{Y}_2^2)^{½}} = \frac{1}{(1 + \frac{1}{(\frac{S}{N})_x^2})^{½} \cdot (1 + \frac{1}{(\frac{S}{N})_Y^2})^{½}}$$

where $$(\frac{S}{N})_y^2 = \frac{\overline{Y_1}^2}{\overline{Y_2}^2}$$

and $$[k_1 = \Gamma_c \cdot (1 + \frac{1}{(\frac{S}{N})_x^2})]$$

X_2 is often set equal to 0 in the Literature, there being obtained the equation

$$\beta^2 = \frac{\overline{Y_1^2}}{\sigma_y^2} = \frac{\sigma_y^2 - \overline{Y_2^2}}{\sigma_y^2}$$

where β^2 is an expression which denotes how large a part of the variance in Y can be related to the dependency on X.

Since when making the correlation, it may be difficult to define just how much of the noise lies in X and in Y respectively, the whole of the noise can be allocated to the XY-correlation in accordance with

$$\beta^2 = \frac{1}{1 + \frac{1}{(\frac{S}{N})^2}}$$

$$\left(\frac{S}{N}\right)^2 = \frac{\beta^2}{1 - \beta^2}$$

Within the vehicle traffic field, σ^2 is normally proportional to the mean value and the measurement time concerned. In view of this, it is possible to distribute noise in a stereotype fashion between X and Y, from

$Y_1 = k_1 X_1$ according to

$$\left(\frac{S}{N}\right)_x^2 = \frac{1}{k_1} \left(\frac{S}{N}\right)_y^2$$

and $$\left(\frac{S}{N}\right)_x^2 = \frac{\beta^2}{1 - \beta^2} \cdot \frac{k_1 + 1}{k_1}$$

for large values of β.

The correlation coffecient β can thus be expressed as a function of the signal/noise ratio on respective links corresponding to the values X and Y. The correlation can be improved by improving the signal-noise ratios.

When the sister links have different correlation coefficients, different signal/noise ratios, the measurement values will not preferably be added straight ahead, but that those values which have a better signal/noise ratio ~~will preferably be weighted higher than the others.~~

Optimal weighting is effected by multiplying the X-values with a factor

$$\alpha = \frac{\left(\frac{S}{N}\right)_x^2}{\left(\frac{S}{N}\right)_z^2}$$

in relation to a selected reference station, (Z).

The new signal/noise ratio will then be

$$\left(\frac{S}{N}\right)_s^2 = \left(\frac{S}{N}\right)_x^2 + \left(\frac{S}{N}\right)_z^2$$

This weighting method also enables contributions to be obtained from weakly-correlated system links.

In the aforegoing, sister links were defined as links which have good correlation between respective traffic parameters. On the other hand, it is not certain that the deviations from the historical mean values of respective links are equally as well correlated. It is reasonable to assume that traffic will fluctuate randomly around respective mean values and that these fluctuations need not have their cause in a source which is common to several traffic routes. In the aforegiven expression $\delta Y = Y_1+Y_2$, where Y_2 is one such random variation that cannot be predicted from the sister links. The best possible prediction is $Y_1 = k_1X_1$, where $X_1 = \delta X-X_2$ and X_2 is unknown. When predicting Y_1, the contribution from δX is obtained from

$\alpha_1 \cdot k_1\delta X = \alpha_1\ k_1\ (X_1 + X_2)$. Taken together it is predicted that $Y_1 = \dfrac{\Sigma\delta Y + \alpha_i \cdot k_i \cdot \delta X_i}{\sum\limits_i 1 + \alpha_i}$

where standardization has been chosen with regard to δY, which in the illustrated case symbolizes prediction from sensors on the same traffic route. The factor k_i is often replaced in practice with Γ_i.

The mean values of the variations X_2 and Y_2 can be estimated from the traffic distribution function. When δX is small, i.e. smaller than or roughly equal to the mean value X_2, it is not worthwhile in practice to predict δY to anything other than $\delta Y = 0$, knowing that

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the mean variation is roughly Y_2. Lower limit values are obtained when selecting more sister routes. Nevertheless, it is important that δY can be predicted quickly when the measured value of δX is large. A large value of δX need not mean that δY becomes large. When several sister routes simultaneously give large δX-values, this indicates that a probability of a common change in the traffic is greater. The nature of this change may be unknown at the moment of making the prediction and a prediction of δY can nevertheless be made on the basis of the relationships between the different sister routes, which can be calculated from the measured values. It should be noted that the relationships now obtained may be different to the relationships earlier obtained and applicable to the more standardized δX-values.

When traffic on a road link increases towards saturation, i.e. towards link capacity, the traffic flow will increase slowly and when δX and δY describe deviations in traffic flow (I), there is obtained another factor k_1 as the relationship between Y_1 and X_1. On the other hand, when δX and δY denote traffic density (P), the traffic density P can continue to increase as a result of higher traffic pressure, even when the traffic approaches maximum capacity. At high traffic flows, vehicle density P can be a more suitable measurement of traffic than the traffic flow.

When predictions from, for instance, traffic on sister links show high traffic flows, close to saturation, on the link selected, it is appropriate to investigate the situation upstream of the link. The high traffic flow is most often the result of the combination of flows from two links, and the point at which these links merge or intersect is normally a narrow sector. If this is so, traffic will congest at the road-merging or road-junc-

tion point. Traffic speed falls and the flow decreases, resulting in tail-backs or queues on one or both of the part-flows. In this regard, the traffic flow at the road-junctions may be considerably lower than the capacity of the following or downstream link, and the flow on this link will be lower than the aforesaid first predicted flow. Traffic on the selected link may flow well, with a good speed. On the other hand, the traffic flows upstream of the entry roads may be much lower, due to traffic congestion.

The prediction of traffic flow on one link is not an isolated process, but requires continued analysis of the traffic flow both upstream and downstream of the link, in order to identify the risk of traffic building-up and therewith altering the first "primary" prediction.

Since it can be expected that not all links are equipped with sensors for economic reasons, there are required auxillary functions which describe how traffic changes over a road section which includes exit and entry roads between two sensor-based links.

A transfer or propagation function $W(X,t)$ describes how vehicle density (flow and speed) changes as a function of distance and time along a road section, for instance a change in the flows I_1 and I_2 from one measuring occasion at (X_1,t_1) to a measuring occasion downstream at (X_2,t_2). We also have functions $\phi(t)$ and $\theta(t)$ which describe changes at approach roads and exit roads. The traffic thins at road exit points by on mean the same factor. At approach or entry points, however, it can be expected that the traffic will need to adapt to the major road when entering from an approach road. As a result, the I_2-term should be smoothed-out slightly when traffic on the major road is high.

These functions ($W(X,t)$, $\phi(t)$ and $\theta(t)$ can be calculated from measurements taken on concerned routes. If the exit and entry points are not equipped with sensors, predictions can be made by applying the same method as that described for sister routes, i.e. by making comparisons with equivalent exit and entry points.

When high traffic flows are measured on a traffic route in (X_1,t_1), $W(X,t)$ can describe disturbance growth and the increased probability of the formation of tail-backs and traffic congestions when traffic flows are close to the capacity of the route. These growth functions can be measured and plotted to predict traffic conditions downstream of a link equipped with a measuring sensor.

In expressions of the kind $Y(Z_2, t_2) = W(Z, t) \cdot X(Z_1, t_1)$, we have earlier used the term Γ instead of W to describe the prediction of Y at a point downstream of the measurement X. The term Γ is obtained from assumptions of linear correlation between the values Y and X, or δY and δX.

The term W may be used more freely to describe a transformation of traffic from one place to another place at a time (t_2-t_1) later on.

For instance, the flow term $I_2(Z,t)$ can be given a ~~continuous variable function where~~

$I_2(Z,t) = W(Z,t) \cdot I_2(0,0)$.

In a first approximation for small t, $W(Z,t)$ can be given a linear growth function where $W(Z,t) \approx (1+\alpha_1 t) \cdot f(Z-vt)$.

When the flow of traffic I_0 on a traffic route approaches the capacity of the route, it can be expected that small I_2-termer will grow as functions of time

and at a growth rate which is dependent on the factor I_0/C. The term W can then be comprised of a function $I_2(Z, t)$ which describes "disturbance" I_2 in movement along the route and a function $f_2(I_0, t)$ which describes growth of the disturbance. In the case of small time periods, the function f_2 can be approximated with a linear function, of t, i.e. $f_2 \approx (1+\alpha_2 t)$, where α_2 is a function of I_0/C. The function $W(Z,t)$ which describes how "traffic disturbances" I_2 grow, can be defined by measuring I_2 along routes for different I_0/C. Corresponding functions for the I_1-term can be obtained in a similar fashion. Measurements can also identify those levels on I_0, I_1 and I_2 at which traffic congestions will normally occur, and consequently the function W is of interest in predicting traffic along traffic routes, particularly when there are not many sensors along the route. In this way, measurements carried out on a highly trafficated route can be used to predict risk locations along the route at which traffic congestions are likely to occur.

So that entries and exits can also be taken into account, measurements are made for defining $\phi(t)$ and $\Theta(t)$. It is assumed in this regard that $\Theta(t)$ will give a percentile thinning of the traffic, whereas the approach problems, and therewith the function $\phi(t)$ become more complicated.

$\phi(t)$ will in some cases generate congestions, particularly at high I_0-values on the route, and to some extent will also equalize existing I_2-variations, by adapting traffic to some extent at the approaches. $\phi(t)$ can be determined more easily and will provide a smoother flow on the route, when "ramp-metering" is applied at the approach.

It is of particular interest to identify by measurement those flow values on the route where there is a danger that the approach flow will result in traffic congestions.

The arrangement, or system, will now be described generally with reference to Figures 1 to 6.

Figure 1a illustrates a simple model of a traffic control centre. In the case of large towns and cities, the traffic control centre will include a large number of operator sites and the control centres will be similar to those control centres used in National Defense systems, such as air defense control or marine control systems. These control systems are constructed to satisfy high demands on real-time performances and modern-day systems are comprised of distributed data processing architectures.

Figure 1a illustrates some essential building blocks of the control centre. "Sensor communication" (4) receives sensor inforamtion from the road network and "Control means communication" (5) transmits resultant procedure information from the control centre. The "Operator" (2) fulfils an important function in the operation of the control centre. He/she inserts information concerning incidents and events reported to the control centre, so that the "Traffic model" (3) is able to take into account corresponding changes in the capacity of the roads, highways, etc., when calculating and predicting traffic flows. Relevant and predicted traffic situations may also be presented to the operator, who then makes a decision concerning the procedures or measures that should be taken.

Much of the historical information relating to the traffic on the different links of the road network at different times is stored in the "database" (1).

Those calculations of traffic parameters that are required to make relevant or current predictions are performed in the "traffic model unit". Since many calculations are required to predict traffic situations on a large road network, it is necessary that these calculations and predictions can be made very quickly. The predictions shall be updated successively and constantly kept current. The real-time requirement will be apparent in the application concerned, and the traffic model unit is constructed so as to provide quick access to local data areas, utilizing powerful computer capacity and a real-time operative system. Examples of building blocks in present-day technology are IBM's RS6000 and the AIX operative system, or SUN's corresponding Unix-package with Sparc-computer and Solaris.

Figure 1b illustrates an approximate structure of the processing unit, in which a control processor (6) communicates with the unit (7) through an address bus (10) and a data bus (11), wherein the unit (7) stores data used in the arithmetical unit (8) and wherein an In/Out unit (9) communicates with other units, for instance through the medium of a LAN.

Figure 2 illustrates the information flow when Predicting and Updating between different functions blocks. These blocks relate to Sensor Information (12), shown in Figure 3, Prediction (14), shown in Figure 4, Updating (15) shown in Figure 6, Database (13), in which large amounts of data system information are stored, and a block (16) which relates to continued procedures, such as Control or traffic related information. New measurement values obtained from the sensors are compared with

earlier historical values which have been taken from the database to the local data area of the traffic model and new predicted traffic parameters are generated on which control decisions can be taken.

The new measurement values are also used to calculate new updated historical values and these values are stored in the data area concerned for immediate use, or alternatively are stored in the database for later use.

As illustrated in Figure 3, sensor information obtained from the road network sensors (17) are transmitted to the control centre and subsequent to being received (18) are either filtered (19) or the mean values of differently time-varying parameters are formed. These sensor information may consist of traffic flow, traffic density and/or traffic speed. The traffic parameters concerned are transmitted to the prediction function (14).

Figure 4 illustrates a first stage of the prediction. Data is sent to Analysis I (21) from the Data area (20). According to one embodiment, this data consists of historical data, X_H, capacity C, standard deviations, σ and status symbol, S. Processed measurement data is obtained from sensor information. Measurement data is compared with historical data in Analysis I and a decision is made as to whether or not the measurement values shall be further processed for prediction purposes. During the greater part of the day, the traffic density of the majority of road links is so low as to enable link times, mean speeds, etc., to be added to the basic values of respective links. Consequently, it is important to sort out quickly those values which do not need to be further processed for prediction purposes. In a number of cases, it may be sufficient to make a comparison with a limit value, X_c, where $X<X_c$ denotes prediction according to a basic value.

On important routes, it is of interest to establish whether or not the measurement values lie within the statistical result $X_H-\alpha\sigma<X<X_H+\alpha\sigma$, where σ is the variance and α is a chosen factor, for instance 1.7. A value which lies outside this interval may indicate an occurrence which requires separate analysis. If X lies beneath the interval, this may be due to traffic obstruction upstream of the link, and the status variable S is encoded for upstream links. The operator can be informed with a warning symbol and the link can be registered on a monitoring list.

If X lies within the current result range and the status variable has been encoded as "OK", the basic values are accepted as a prediction. Other examples of encoding S are

S = 0	"OK". Select the basic values.
S = 1	Danger of disturbances in traffic on another route.
S = 2	Danger of disturbances in traffic on the local route.
S = 3	Serious danger of traffic disturbance.
S = 4	Warning (set from another route).
Etc.	

A more accurate analysis may be needed when S>0, for instance when an analysis shows that traffic approaches the capacity limit. When "Analysis I" indicates that a prediction calculation shall be carried out, additional information is introduced into "Calculation I", (22). Calculation I is supplied with further prediction values, namely the prediction factor and when appropriate the signal-noise ratio S/N for the prediction parameters. The result is a first traffic prediction based on the individual sensor information.

Predicted link data obtained from several sources can be calculated in accordance with Figure 5.

The value predicted for the link concerned $Y_1(t_p)$ is obtained from the measured values from the same route $Y(t-\tau_0)$ and the sister route $(X_1(t-\tau_1), X_2(t-\tau_2)$, and so on. The values of respective routes are multiplied by the factor Γ_i/k_i and are added to give the result $Y_1(t_p)$. The factor k_i is the weighting factor which relates the contribution of each route to its signal/noise ratio or to some corresponding correlation coefficient. Figure 6 shows that the preceding historical value $X_H(0)$ is updated by forming δX from the difference between the current measurement value and the historical value, whereafter the new historical value is formed by adding $\delta X/k$ to the old value. The factor k determines the time constant for the length of time taken before a change in the measurement values results in a corresponding change in X_H. In this case, the historical value X_H is not a mean value where a plurality of the measurement values have the same weight when forming a mean value, but that the factor k gives a greater weight to the present input values than the earlier values. The updating method is simple, since it is not necessary to save more than the current value.

Figure 7 illustrates how the correlation coefficient and the prediction factor can be obtained from the signals X and Y. The top of the Figure shows the values of Y and X being inserted into a respective register. Corresponding values X_i and Y_i are multiplied together and new pairs for multiplication are obtained by shifting X_i and Y_i relative to one another. By successively shifting, multiplying and summating these values, there is obtained a series of values which have a maximum at displacement τ between the Y and the X values.

It has been assumed in the illustration that the changes in $\bar{X}$, $\bar{Y}$, σ_x och σ_y are small during the operation of the relative shifts of Y and X. In another case, the whole of the correlation coefficient β can be calculated for each shift and the maximum β-value is sought to determine the τ-value.

Figure 7 also shows how statistical basic parameters are obtained for the parameters X and Y. The expression for correlation coefficient and correlation factor is repeated at the bottom of Figure 7, to facilitate an understanding of the relationships between the parameters illustrated.

One reason for predicting traffic situations is to be warned of the risk of overloading or traffic congestion in good time, so that measures can be taken to avoid the predicted traffic congestions. Certain traffic congestions cannot be predicted and occur without warning. For instance, there may be a road accident, the engine of a vehicle may stall or a truck may lose its load and block the road. It is necessary to be able to detect this type of problem as soon as possible, and to be able to predict the new traffic situation that occurs and which may be influenced by procedures from traffic operators, police, and so on.

Detection of a new situation and the localization of the source of the disturbance are effected with information obtained from measuring sensors and by comparison with historical values. Normally, traffic upstream of the disturbance will become more dense while traffic downstream of the disturbance will become more sparse, and traffic located upstream exit roads to alternative roads will become more dense.

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An alternative information source consists in external messages, such as telephone calls from drivers of vehicles, police, etc., informing that an accident has occurred and passability on the route concerned is restricted to about X%.

When sensors are located both upstream and downstream of the incident, a direct measurement of the capacity at that time is obtained. A prediction of the new traffic situation can be made immediately, by initiating a number of activities with the aim of obtaining quickly a rough prediction which can be later refined as new measurement data successively enables better predictions to be made. The new traffic situation tends to stabilize after an initial dynamic happening or occurrence, and the prediction process then becomes simpler. Many disturbances resulting from minor traffic accidents, stalled engines, etc., block the route for less than 5-15 minutes, and the duration of the disturbance will depend on the traffic intensity at that time and the tail-backs that are formed and the time taken for these tail-backs to disappear. It is seldom that such disturbances will attain a stable phase, but should be treated entirely as belonging to the first dynamic period. The following examples illustrate how the arrangement or system operates to give predictions in current or prevailing situations.

Assume that a link is blocked to 100% by an incident. This situation is detected in accordance with the aforegoing and since there is generally found in the vicinity alternative routes, or detours, that the traffic can follow to circumvent the blocked link, a simple function can be used to make a first redistribution of the traffic which would otherwise have passed along the blocked link.

A cost measurement can be obtained for each examined route, with the aid of a "cost function" where travel time and possibly also parameters such as road distance and road size, etc., are added to cost parameters. The difference between the 1-3 best routes and remaining routes will normally be so great as to enable the remaining routes to be ignored in a first stage in which the traffic attempt to circumnavigate the incident on the alternative routes judged to be the best, which tends to result in an overload on the best alternative and successively increased traffic on the next best alternative, and so on.

The traffic is divided in the calculating unit of the arrangement in accordance with the above, so that when the best alternative route is loaded with so much extra traffic that its cost value increases, traffic is distributed to the next best route, and so on. When the traffic to be redirected is very considerable and the alternative route is already heavily trafficated, the first redistribution will predict the occurrence of tail-backs and traffic congestions, wherewith the traffic control operator is warned to this effect and may be given suggestions as to which measures or procedures should be taken, for instance measures which will inform motorists at an early stage, upstream of the blockage, through the medium of information, variable message signs, etc., redirecting the traffic to other routes.

If possible, the traffic flows should be kept at a safe margin from maximum capacity, to avoid traffic congestions. As before mentioned, it is very important to maintain traffic flows beneath traffic congestion limits. The road network will then be used to a maximum. Passability is considerably impaired when traffic congestions occur, and the capacity of the road network

is reduced when it is best needed. If traffic redistribution does not suffice, the next best alternative is to slow down the traffic flows at suitable places upstream of the disturbance source. For instance, it is better for traffic to queue on an entry road in a suburban area than to allow traffic to approach the city or town centre, where queues would increase blocking of other important traffic routes where a high capacity is still more essential.

As the aforesaid first prediction is made by rough redistribution or rerouting of the traffic, the new traffic situation that arises is determined by existing sensors, and those sensors which are located at the beginning of the alternative routes provide information as to how the traffic flows are actually distributed. The measured values are used to correct the allocated traffic distribution and to predict the traffic on the alternative routes downstream of the sensors.

High frequency components of the type I_2, P_2 and I_1, P_1 are used to obtain the traffic distribution measurement values quickly. These parameters constitute characteristic traffic patterns and can be recognized along a route and also correlated with corresponding components of the primary route. The measurements are also able to show from this how much of the traffic on the primary route has elected to take respective alternative routes.

The control measures taken by the operator are coupled to the prediction unit of the system as supplementary information concerning an anticipated control effect or redistribution of traffic, and hence a new prediction is made with respect to these values. In the next stage, measurement values are obtained which disclose the actual traffic redistribution situation, whereafter a new prediction is made, and so on.

Particular attention is paid to the sensors located around the incident location, so as to be quickly aware of when the traffic begins to move on the earlier blocked link, whereafter traffic prediction returns to normal.

In the case of short-term incidents, the dynamic change in traffic can often be considered as local, i.e. the main change in traffic flow occurs within an adjacent restricted area around the incident. This area is comprised of a few links upstream of the incident and including exit roads for the best alternative routes, via the alternative routes to and including entry routes to the blocked route downstream of the incident. In the first approximation, traffic can then be considered to flow roughly as normal. There are a further two reasons why the traffic readapts downstream of the blocked link. Firstly, part of the traffic upstream of the blockage or incident have a destination on the actual route concerned, so that the best route selection is to return to the same route downstream of the incident. The other reason is because the alternative routes are heavily laden with traffic, causing traffic to endeavour to return to the blocked route, downstream of the blockage or incident and therewith utilize the better passability of this route.

If the final destination of all vehicles was known at each moment in time, it would be possible to calculate a more precise route selection for the individual vehicles concerned and the gathered traffic flows could be calculated for the new traffic situation. A valid O/D-matrix would be a good starting point in this regard.

Predictions can also be made more precise by assuming that the disturbances are, in the main, local and to

construct databases for local traffic flow distribution. Components of the type I_2 and I_1 can be used in this regard, as previously mentioned. For instance, the measurement values on the link concerned can be correlated with the measurement values on different alternative routes downstream of the link, so as to obtain an assessment of the percentage of traffic flow on the link concerned divides onto respective alternative routes downstream of said link.

When an incident occurs on the link concerned, the "cost calculation" for alternative routes may take into account knowledge of downstream traffic distribution and therewith sometimes provide a better prediction of the traffic distribution on the alternative routes.

CLAIMS

1. A method for determining traffic parameters such as traffic flows, speeds, car densities and link travel times by means of sensor information obtained from different measuring sites in a pertinent network, wherein a number of the sensors produce at least two of the parameters traffic flow, traffic density and vehicle speed or alternatively link travel time, **characterized** by predicting a traffic parameter Y on a pertinent link at a time τ on the basis of sensor information X measured earlier on another link; relating the prediction factor to a corresponding correlation coefficient through the medium of the covariance and basic statistical parameters; determining prediction accuracy by the correlation between the corresponding parameters X and Y; improving correlation by filtering sensor information obtained from a number of sensors through at least two, preferably three, time stages of mutually different lengths such as to produce components which describe respectively slower and faster variations of said parameters; using only components which describe slower variations to predict traffic between different routes or between historical mean values; and using components which describe faster variations to make near time prediction of the traffic along the same traffic route or a selected route; and determining respective prediction factors for corresponding frequency component - combinations.

2. A method according to Claim 1, **characterized** by collecting historical mean values X_H and the prediction factor Γ from the data area of a prediction unit to predict the corresponding traffic parameters on the link concerned, whose measured value Y is later obtained, wherein the values of the new pair of X and Y is used to update the corresponding X_H and Y_H respectively and these values are stored in the memory area; wherein subsequent

to having obtained the required value sequence, the prediction factor is updated using the new X_H, Y_H values; wherein when requiring a prediction of deviations from the historical mean value, deviations are created between the current sensor values and the historical values and a prediction factor for the deviation from Y_H in relation to the deviation in X_H is created and updated, and wherein the traffic parameter Y of the link concerned is predicted as Y_H plus the predicted deviation from Y_H obtained from the current deviation in X from X_H with the aid of the associated prediction factor.

3. A method according to Claim 2, **characterized** by setting the prediction factor Γ to equal $\beta \cdot \sigma_y/\sigma_x$, where σ_x and σ_y are standard deviations for the related parameters X and Y and where β is the correlation coefficient, or determining Γ directly as the waiting value for X, Y in relation to the waiting value for X^2, wherein the time derivatives for the $X_H(t)$ and $Y_H(t)$ graphs are considerably larger than a selected limit value and the prediction factor Γ is set in a corresponding relationship between the X_H and Y_H time derivatives, and wherein the prediction factor obtained from the time derivatives can be combined with the prediction factor obtained from the amplitude values.

4. A method according to any one of Claims 2-3, **characterized** by transferring valid values from the computers to the prediction unit such as to update the stored parameter values; adding the new updating values to the valid values according to the example $X_H(1) = X_H(0) + (X - X_H(0))/k$, where k is a constant which determines the sensitivity to changes; and updating the prediction factor Γ by updating the corresponding factors one by one according to what has been mentioned above before establishing any quotient, wherein the number of parameters that need to be stored is limited in comparison

that need to be stored with a true establishment of the mean value.

5. A method according to any one of Claims 1-4, **characterized** by determining the prediction factor for a time shift τ between the values of X and Y which corresponds to a maximum of the correlation coefficient, wherein the prediction factor is obtained when X and Y are present on one and the same route, normally at that τ which is obtained as a time difference by following the traffic downstream between X and Y; and wherein τ is obtained when X and Y are present on mutually different routes, probably when X is present in a corresponding time phase upstream of Y.

6. A method according to any one of Claims 1-5 in an environment in which the number of sensors is limited and where no sensor data is obtained from the link concerned, **characterized** by storing historical values together with the prediction factor for the link concerned related to the sensor data for another link and using relevant values from said last-mentioned link to predict the traffic on the link that has no sensor and updating stored values for the link concerned by taking occasional measurements or making operator corrections.

7. A method according to any one of Claims 1-6 in an environment where several links are without any sensor, **characterized** in that a propagation factor (W(z, t) is calculated in the prediction unit for the traffic parameter in question, e.g. the flow term I_2 from measured values from two sensors separated in space and in traffic propagation time with z and t respectively according to $W_2(z, t) = I_2(z, t)/I_2(0, 0)$ and where the measurements of different sensors at different distances and different traffic flows are providing a function $W(z, t) = f_1(t) \cdot f_2(z-vt)$, where $f_1(t)$ can be adapted to

the measurement values by means of the least square means and where $f_1(t)$ usually is set as a linear function $(1+\alpha t)$ or for large growth factors exp? (α, t), where α is depending of the flow I and the capacity C and where the relation is set equal to $\alpha(I/C)$ and where W(z, t) can be used to predict the flow along longer distances without any sensor and where W(z, t) is updated successively to new situations on the route in question by calibrating it to correspond existing sensors, and a more general setup (W(z, t) can be calculated by adaptation to measurement values from several routes and stored and used for predicting on routes, where direct sensor data are missing, and where W(z, t) is especially interesting during high traffic flows, when W(z, t) can predict decreasing traffic flows due to increased car density and queuing up.

8. A method according to any one of Claims 1-7, **characterized** in that the changing factors ϕ and θ are calculated in the prediction unit for any actual traffic parameters, such as the flow term I and where ϕ then is related to the change in flow δI_L on the route as a result of the flow I_t on a ramp and θ is related to a corresponding change at an exit and $\phi = \delta I_L/I_t$ is obtained from the measurement values by an adaptation corresponding to W(z, t) of Claim 7 by a linear function $(1+\alpha)$ or exp α and $\alpha(I/C)$, and where ϕ is especially interesting at high traffic flows, ϕ providing a prediction of a possible traffic jam.

9. A method according to any one of Claims 1-6, **characterized** in that the parameter Y for the link in question is predicted by sensors on a number of different links, the links possibly being both a link on the same route as the link in question and a link on another route identified as sister route, the historical traffic parameter values of whose have a correlation with the

link in question and that the prediction from several sensors is used to obtain a large measuring volume and a good prediction safety during a shorter time period.

10. A method according to Claim 9, **characterized** in that the prediction value from sensors on different routes are combined regarding the correlation being different between different link values (X) and the link in question (Y), and valuating factors then are used for a corresponding prediction, where the valuating factors are related as a signal/noise ratio in square for the corresponding link, and where the signal/noise ratio for a link relates to the signal/noise ratio in the correlation between the link X and the link in question Y and can, e.g., be approximated according to

and $$\left(\frac{S}{N}\right)^2 = \frac{\beta^2}{1 - \beta^2} R_1$$

where R_1 is a correlation factor taking account of the noise in the independent variable and where $R_1 = (K_1 + 1)/k_1$ is corresponding to a normal noise distribution, k_1 being the linear prediction factor.

11. A method according to Claim 9 or 10, **characterized** in that the predictions of the sister routes are compared, and if any or several routes are significantly differing from the others, an incident or any special circumstances on a differing route or on differing routes, this possibly comprising an incident detection triggering predetermined activities, and for several differing routes, where the differences are correlated to each other, these routes can be selected to predict together the new situation on these routes.

12. A method according to Claim 9, 10 or 11, with sister routes made up of selected entrance routes to a city and where the measurements during a certain period, e.g. the

morning hours, are used to predict the traffic later on during the day in the town centre and for even longer prediction intervals for the exit traffic during the afternoon and where the sensor information from the entrance route the town centre and exit route respectively are used to update historical values and the prediction factors according to any previous Claim.

13. A method according to any one of the preceding Claims, **characterized** by that the information from a sensor is used to predict the traffic at the same spot and that this prediction is related to a short time perspective related mainly to I_2 and I_1 type components and provides additional information of traffic disturbances on the link in question.

14. A method according to any one of the preceding Claims, **characterized** by that a growth function U(t) is calculated in the prediction unit and comprises factors such as exp t/τ, t and exp t/τ_a for the corresponding growth and decay of the traffic distribution for selected parts of the street net and where the time constants are measured under different circumstances for different ratios of various I/C values and where these time constants can be used to predict the traffic for different events such as the period before and after a football match, traffic jams, etc., and that U(t) is stored for various events and that the new event's course can be predicted by means of interpolating or extrapolating U(t) to the situation in question.

15. A method according to any one of the preceding Claims with sensors being placed on given routes being used to predict the traffic on other parts of the road net, target links, **characterized** by that the primary prediction values are treated by a filtering function with the target link time constant before any final

prediction result is obtained, the traffic on the given routes possibly varying with time constant being faster than those valid for the target links.

16. A method according to any one of the preceding Claims, **characterized** by that any prediction of any complete subareas of the street net is made by one or several chosen sensors by means of a correlation with the measurement values obtained from one or several measurements in the street net.

17. A method according to any one of the preceding Claims, **characterized** by that the nearest entrance link upstream is analyzed when the predicted traffic on a link is reaching the link capacity to determine if this implies a narrower section than said link and if the connecting flows at the intersection are a big risk for traffic jams when vehicles are weaving into the link, and if so the analysis continues upstream on both the link and the entrance link to analyze the secondary effects on traffic jams and to predict the traffic downstream the traffic jam with a correspondingly lower traffic being limited by the traffic jam.

18. A method according to any one of Claims 1-17, the method being used in situations where the prediction information on how the traffic will become is used to inform car drivers or to control the traffic by means of signs or signals, the traffic then not developing in accordance with the first prediction, **characterized** in that a new prediction is made with respect to the made actions, e.g. according to the effects of values fed in by the operator or according to stored results, wherein the correlation is calculated between really measured traffic flows and the prediction values which were utilized externally and is used to correct the last prediction action package to a new updated package to be

used and several such relations are stored for selected links and statistical mean value relations are established for various types of situations to be used for corresponding new situations.

19. A method according to Claims 1-8 to predict the traffic, when short term incidents are partly or totally blocking the passability of a link and where the incident can be reported by means of external sources or be detected by sensors, **characterized** in that the detecting is made with sensors available downstream and possibly upstream of the incident and when a relatively abrupt decrease of the flow can be detected by the sensor downstream, indicating a possible incident, and where the new flow provides a measure of the new limited capacity and a new limited area is defined around the incident as a local disturbance area being provided by links upstream of the incident which comprises exit routes for alternative routes and the alternative routes and the entrance routes to the link in question downstream of the incident, and where the best alternative routes are determined by means of a simple valuating function or a cost function, where the travel time period, the travelling route, the road size, etc., can be comprised alternately or in combination and where the costs are initially determined for a few number of, e.g. 1-3, of the alternative routes having the lowest costs and where the traffic distribution is made according to the best alternative route until the costs are increasing, whereafter the next best alternative route also is filled, and so on, balancing the costs and measurements are made, with suitable sensors being available, of the really obtained traffic distribution on the alternative route and the prediction of future traffic conditions along the alternative routes is then corrected or updated .

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20. A method according to any one of Claims 1-19, **characterized** in that one or several high frequency I_2, P_2-type components, possibly in connection with I_1, P_1-type components, are used to quickly provide measuring values of the traffic distribution, and where the correlation of these parameters between the link in question and the corresponding alternative link is used to determine and to predict the traffic distribution between possible alternative routes.

21. A method according to Claim 19 or 20, **characterized** in that one or several of the high frequency components are used to determine how the traffic flow from a link is distributed on alternative routes downstream by means of the correlation between the link and the alternative routes downstream respectively and where such information can be stored for selected links and be used when an accident occurs on the link in question to define alternative routes matching the existing traffic distribution downstream of the incident and also to predict initially any adherent traffic for the corresponding alternative route.

22. A method according to any one of Claims 1-20, **characterized** in that the traffic prediction for an actual link is provided from the sensor values from another link and that the prediction then is related to slowly varying traffic parameters, e.g. Io, P_o, and to these values are added amplitude values of high frequency traffic parameters, e.g. I_2, P_2, being obtained from stored values of measurements of traffic parameter relations, e.g. $I_2(I_o, C)$, i.e. I_2 is measured for various I_o/C values, either on the link in question or the corresponding information is used from another similar link, or, if measurements are not present, the I_2 and I_1 terms can be estimated from standard deviations, σ, from the I_o value during the corresponding measuring periods

T_2 and T_1 which values are providing predicted I-values to be compared with the criteria of the link in question for any risk for traffic jam.

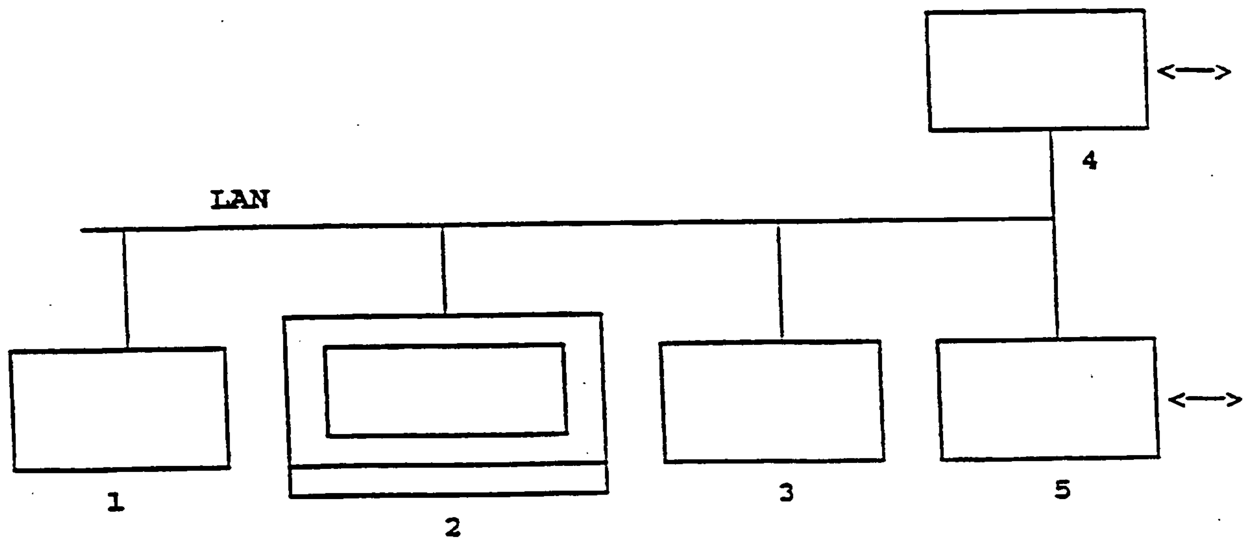

Fig 1 a

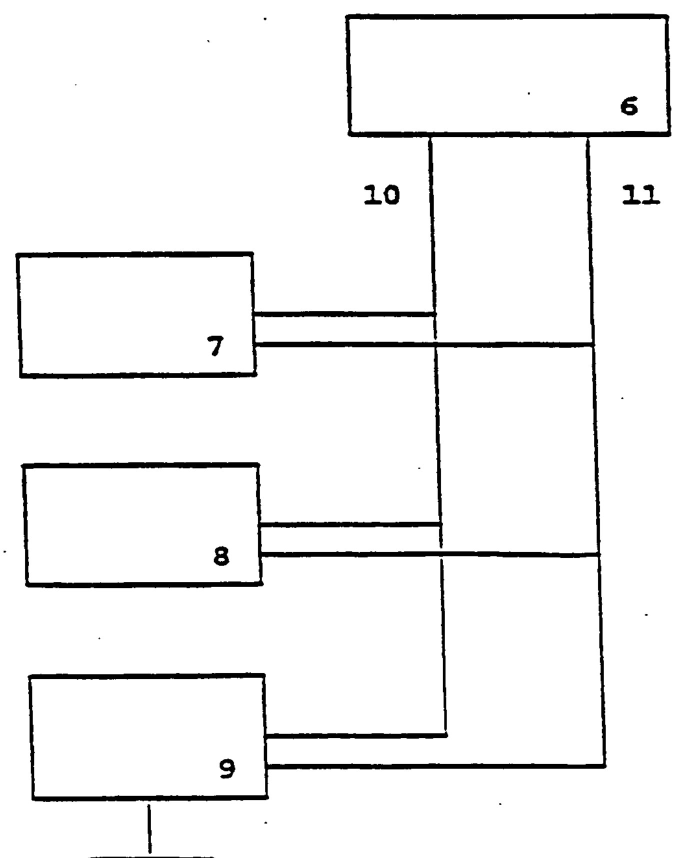

Fig 1 b

BNSDOCID: <WO_________9411839A1_I_>

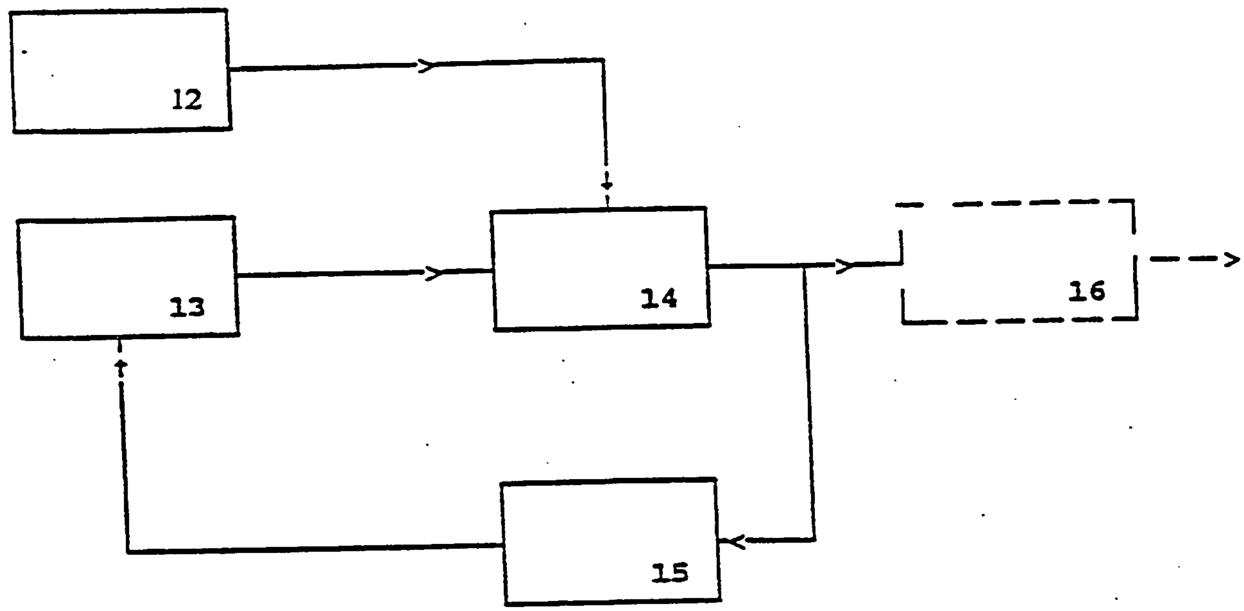

Fig 2

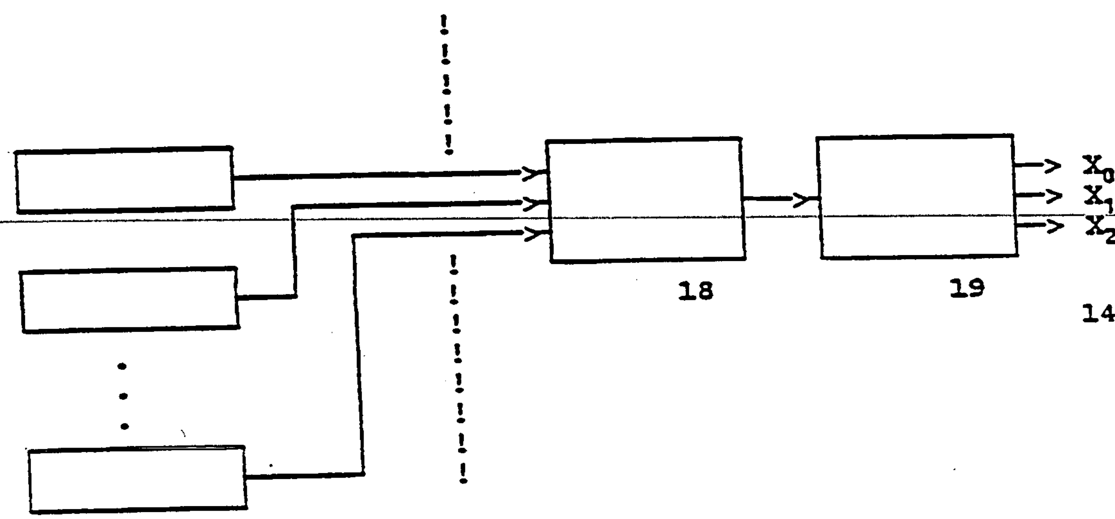

Fig 3

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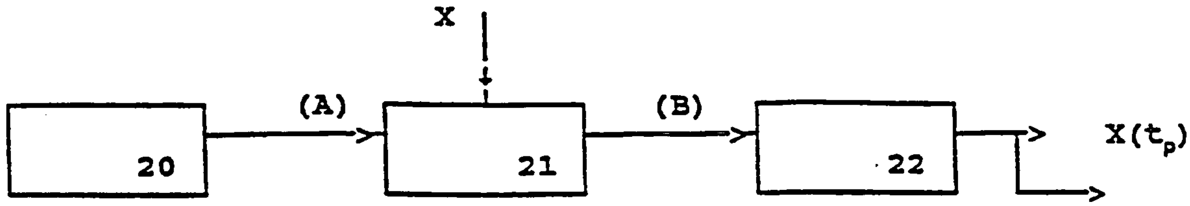

Fig 4

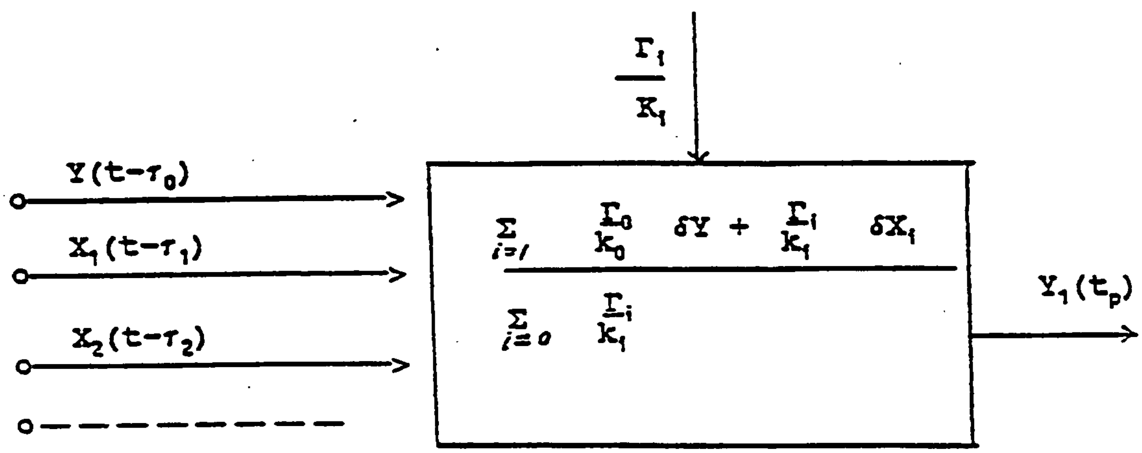

Fig 5

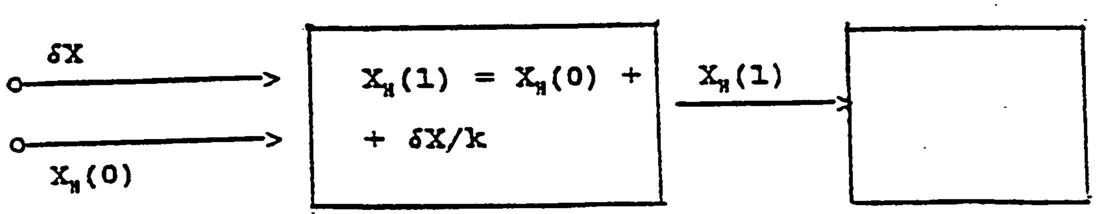

Fig 6

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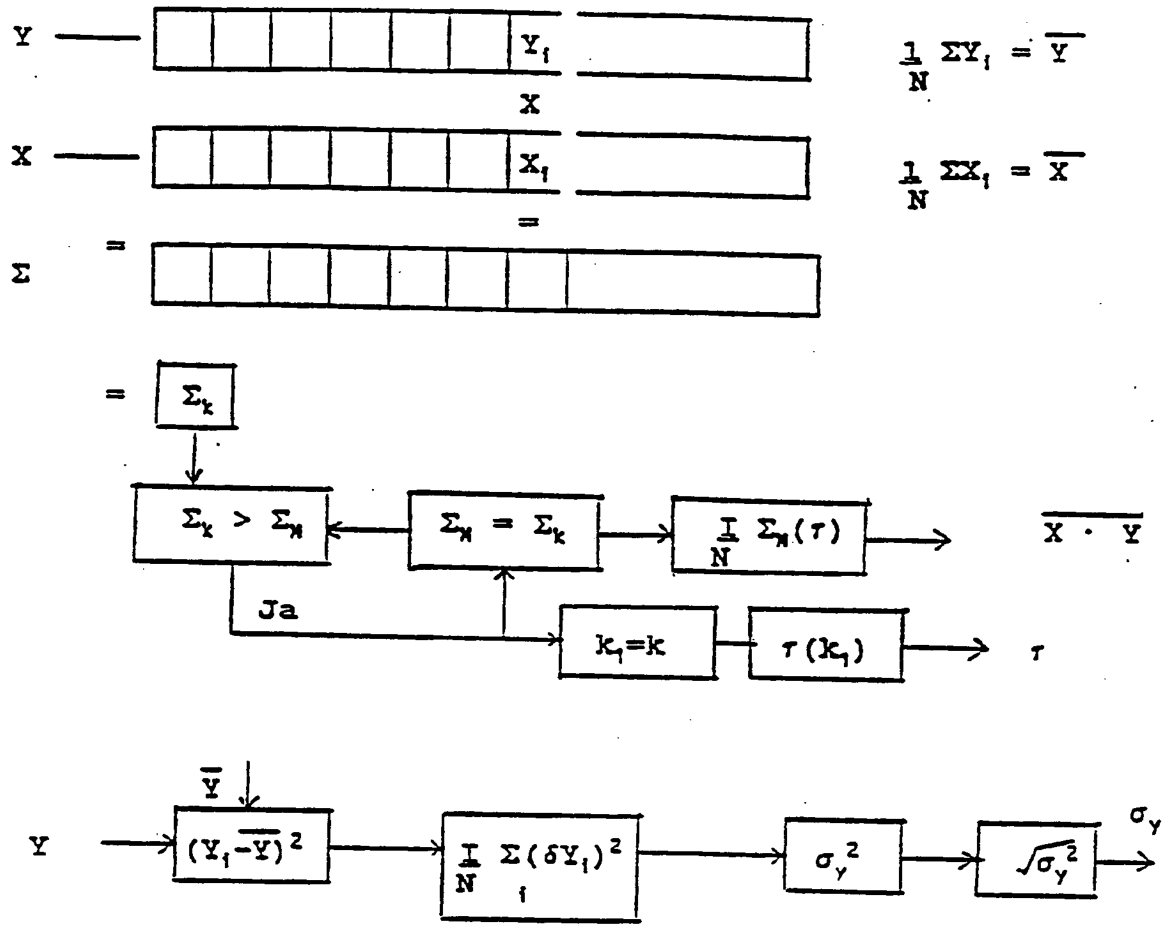

$$B = \frac{\overline{X \cdot Y} - \overline{X} \cdot \overline{Y}}{\sigma_x \cdot \sigma_y}$$

$$\Gamma_c = \frac{\overline{X \cdot Y}}{\overline{X^2}}$$

Fig 7

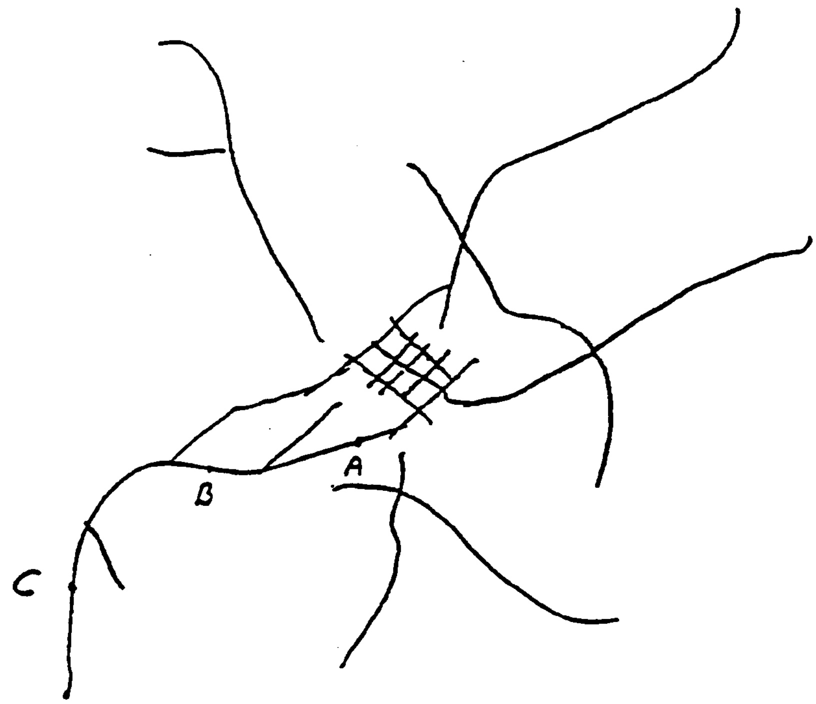

Fig 8

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 93/00962

A. CLASSIFICATION OF SUBJECT MATTER

IPC5: G06F 15/48, G08G 1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC5: G06F, G08G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DIALOG: INSPEC, CLAIMS, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Proceedings of the 1976 IEEE Conference on Decision and Control including the 15th Symposium on Adaptive Processes. 1976, New York, NY, USA. Baras J. S. et al "Filtering techniques for urban traffic data" see page 1297-1298 -- --------	1-22

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 February 1994	02 -03- 1994
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Jan Silfverling Telephone No. +46 8 782 25 00

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